International
Space Station

Mir External Contamination Observations

Presented at the
Space Environments and Effects
Flight Experiments Workshop

June 23-25 1998

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Summary of Mir Observations

International Space Station Program Office

BOEING

International Space Station Requirements

- Total Molecular Deposition of 130 Å/year

Mir Contamination Observations

•Comes-Aragatz (CNES)	350 - 780 Å in 13 months
•Camera Bracket (NASA)	12,000 Å in 4 months
•ICA QCM 1 (ESA)	13,000 Å in 3 months
•ICA QCM 2 (ESA)	14,500 Å in 3 months
•ICA QCM 3 (ESA)	4,500 Å in 3 months
•Trek Blanket (NASA)	> 20,000 Å in 4.2 years
•Astra-II (RSC-Energia)	5,000 Å in 13 months

Mir Contamination Observations
Laboratory Analysis Results

Material Sample	Description	Analysis Technique	Analysis Results	Report Number and Comments
ESEF #1A	Aluminized FEP	WSTF/XPS	Atomic Concentrations: Carbon: 33.2% Fluorine: 65.2 % Oxygen: 1.6 %	WSTF 96-30405 (02/97). No atomic silicon detected. Analysis consistent with FEP Teflon.
ESEF #2AE	Aluminum Coupon	WSTF/XPS	Atomic Concentrations: Carbon: 56.4% Oxygen: 25.2 % Silicon: 3.5 % Aluminum: 14.8 % Nitrogen: 0.1 %	WSTF 96-30406 (02/97) Atomic silicon was detected Analysis consistent with polymethylsiloxane (102.36 eV) Depth Profile Analysis. ~ 400 Angstroms Silicon/Oxygen/Nitrogen Atomic Ratio: 1:7:16
ESEF #1A	Aluminized FEP	Charles Evans & Associates TOF-SIMS	Compounds Detected: C, CF, CF_2, CF_3, C_2F_5, C_3F_5; and C_3F_7	Report dated 10/07/96 No atomic silicon detected. Analysis consistent with FEP Teflon
ESEF #2AE	Aluminum Coupon	Charles Evans & Associates TOF-SIMS	Compound Detected: polydimethylsiloxane ($C_2H_6O_1Si_1$)	Report dated 10/07/96. Atomic silicon was detected. Analysis consistent with polydimethylsiloxane.
Shuttle Docking Module Camera Brackets	A-276 White Paint (Exposed Side)	WSTF/XPS	Compound Detected (1) polydimethylsiloxane (2) silicon dioxide (SiO_2) Atomic Concentrations: Carbon: 47.8% Oxygen: 34.1 % Silicon: 16.9 % Nitrogen: 1.6 %	WSTF 96-29972 (08/96). Atomic silicon was detected. Analysis consistent with polydimethylsiloxane (102.8 eV) and SiO_2 (103.6 eV) Depth Profile Analysis: ~ 12,000 Angstroms Silicon/Oxygen/Nitrogen Atomic Ratio: 1:2.2:6+
Mir Trek 2 Blanket	White Woven MLI Outer Covering (Discolored Side)	WSTF/XPS	Atomic Concentrations: Carbon: 28.0% Fluorine: 18.3% Oxygen: 35.0 % Silicon: 16.7 % Phosphorus: 1.6 % Nitrogen: 0.4 %	WSTF 96-30305 (02/97). Atomic silicon was detected. Analysis consistent polydimethylsiloxane (102.9 eV) Depth Profile Analysis. 1.0 micron (10,000 Angstroms) Silicon/Oxygen/Nitrogen and SiO_2 (103.7 eV). Atomic Ratio: 1:2:1.7
Comes-Aragatz Experiment	Various Materials samples, (113 total)	CNES EDAX/RBS	Compound Detected: (1) V-Side: 780 angstroms of SiOx (silicon oxide) (2) R-Side: 350 angstroms of SiOx (silicon oxide)	SiOx most probably due to orbital oxidation of silicone contaminants outgassed by Mir painted fiberglass structures.

Results

- Contaminant deposit identified as an SiO_x layer superposed with a carbon/oxygen layer.
- Average contaminant deposit thickness measured on the R side was 350 ± 50 Å.
- Average contaminant deposit thickness measured on the V side was 780 ± 50 Å (equivalent to 2.6×10^{-13} g/cm^2/sec).
- The effective outgassing rates to produce the observed contamination were estimated at 3.2×10^{-11} g/cm^2/sec for the R side and 7.1×10^{-11} g/cm^2/sec for the V side.

Location

- Mounted on the Docking Module.
- The camera bracket side with the heaviest amount of contamination had a view of the Spektr module. The side with the lowest amount of contamination had a view of the docking module and the Krystal solar array, with a peripheral view of the Soyuz, Kvant and Mir Core Module.

LEO Exposure Time

- The camera bracket was mounted on the docking module for 4 months, from November 19, 1995 through March 27, 1996.

Results

- Contaminant deposit identified as an SiO_x layer consistent with polymethylsiloxane and SiO_2.
- Measured contaminant deposit thickness was 12,000 Å (sample 001B). This is equivalent to a rate of approximately 1×10^{-11} g/cm^2/sec.
- Exposed samples showed a substantial layer composed of primarily silicon and oxygen in an atomic ratio of 1 to 2. There was a carbon layer at the interface between the top layer and the bulk material.
- Sample 001B showed a a thick layer composed of silicon and oxygen with a carbon-rich layer at the interface with the bulk material. Sample 002B showed two distinct layers composed of silicon and oxygen separated by a carbon layer.
- The effective outgassing rate required to produce the observed contamination was estimated at 1.2×10^{-10} g/cm^2/sec.

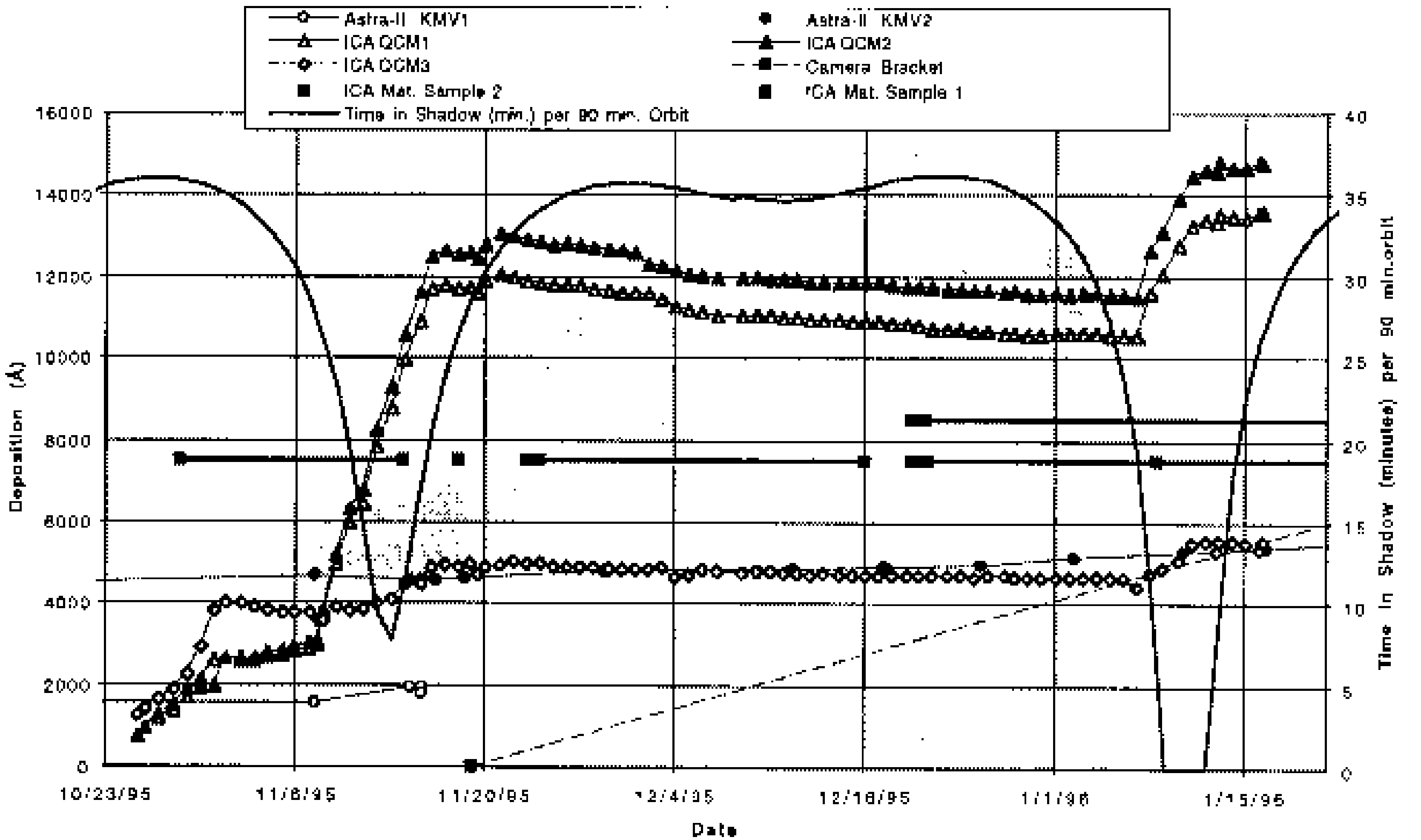
Location

- Part of the Euro-Mir '95 ESEF platform. ICA was located on the end-cone of Spektr module.
- Two Quartz Crystal Microbalances (ICA QCMs 1 and 2) were directed along the Spektr module axis (at the time thought to be facing ram). One QCM (ICA QCM 3) was directed perpendicular to the Spektr axis (thought to be facing the nadir direction).

LEO Exposure Time

- Euro-Mir '95 began in September 1995 and was completed in March 1996. ICA QCM mission data was available from October 1995 through January 1996.

Mir Contamination Observations



View from ICA QCMs 1 & 2

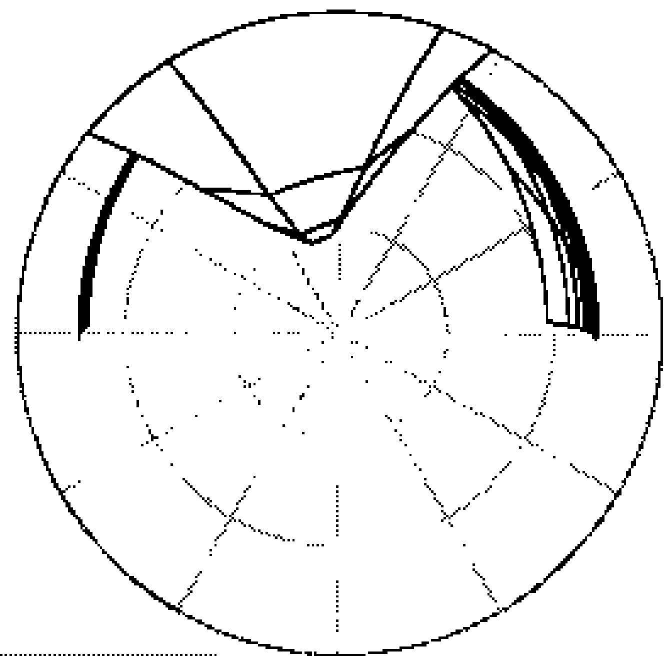
Location: 44, -1, 38

Direction: 0, 0, 1

View Factor to:

Spektr 0.1194549

Spektr SA 0.0225548



Dates	Nov. 7-16, 1995	Jan. 7-11, 1996
QCM 1 deposition rate ($g/cm^2/sec$)	1.2×10^{-10}	7.8×10^{-11}
QCM 2 deposition rate ($g/cm^2/sec$)	1.3×10^{-10}	8.5×10^{-11}
QCM 1 derived Spektr outgassing rate ($g/cm^2/sec$)	**1.0×10^{-9}**	**6.5×10^{-10}**
QCM 2 derived Spektr outgassing rate ($g/cm^2/sec$)	**1.1×10^{-9}**	**8.0×10^{-10}**

ICA Flight Experiment (Euro-Mir '95)

Results

- Significant increases in ICA QCM frequency measurements correlate well with Mir attitude data and increase in temperature due to "solar cycles" (time in shadow).
- Pressure readings from within the Spektr endcone indicate significant materials outgassing from within the non-pressurized endcone.

Dates		Nov. 7-10, 1995	Jan. 7-11, 1996
Observed	QCM 1 deposition rate ($g/cm^2/sec$)	1.2×10^{-10}	7.8×10^{-11}
	QCM 2 deposition rate ($g/cm^2/sec$)	1.3×10^{-10}	8.5×10^{-11}
	QCM 3 deposition rate ($g/cm^2/sec$)	1.8×10^{-11}	3.0×10^{-11}
Derived	QCM 1 derived Spektr outgassing rate ($g/cm^2/sec$)	1.0×10^{-9}	6.5×10^{-10}
	QCM 2 derived Spektr outgassing rate ($g/cm^2/sec$)	1.1×10^{-9}	8.0×10^{-10}
	QCM 3 derived Spektr outgassing rate ($g/cm^2/sec$)	8.9×10^{-10}	1.5×10^{-9}

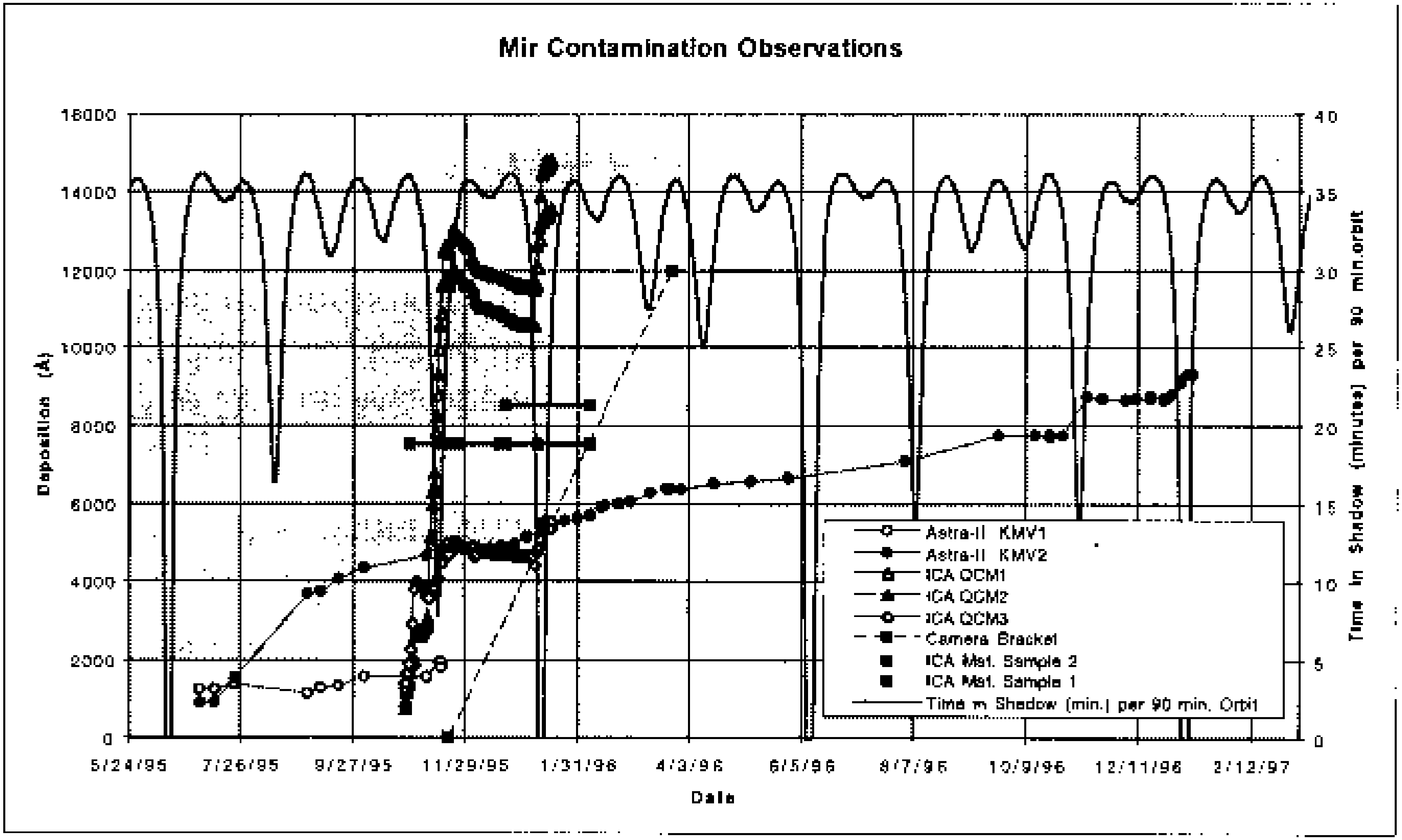
Location

- Astra-II is located on the end-cone of Spektr module, on the opposite side from the ICA flight experiment.
- One Crystal Microbalances (KMV 2) is directed along the Spektr module axis, facing the Mir core. The second QCM (KMV 1) was directed perpendicular to the Spektr axis (Zenith direction).

LEO Exposure Time

- The Astra-II QCMs have been operating since June 1995. Disruption due to Progress impact.

Mir Contamination Observations



View from Astra-II KMV2

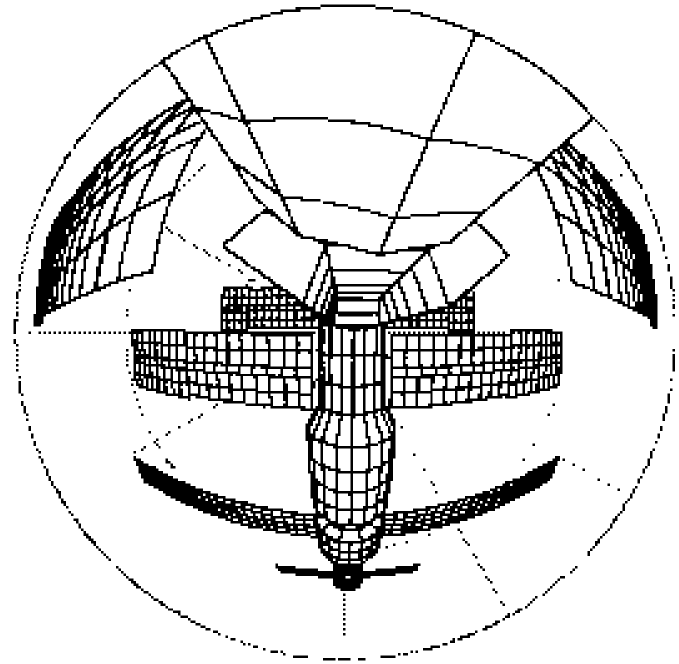
Location: 31, 1, 30

Direction: 0, 0, -1

View Factor to:

Spektr	0.2771924
Spektr SA	0.0413169
Core	0.0845588
Core SA	0.0652032
Kvant	0.0068475
Kvant SA	0.0215639
Progress	0.0011795
Progress SA	0.0012173
Priroda SA	0.0300060

View Factor to Spektr/Core/Kvant: 0.3685985



Dates	KMV2 deposition rate ($g/cm^2/sec$)	KMV2 derived Spektr/Core/Kvant outgassing rate ($g/cm^2/sec$)
7/22/95-9/1/95	6.0×10^{-12}	1.6×10^{-11}
5/29/96-8/2/96	7.0×10^{-13}	1.9×10^{-12}
8/2/96-9/24/96	1.5×10^{-12}	4.1×10^{-12}
10/29/96-11/12/96	8.3×10^{-12}	2.3×10^{-11}
12/27/96-1/7/97	6.6×10^{-12}	1.8×10^{-11}

Objectives

- The Mir Solar Array Return Experiment will assess long-term degradation of Mir solar arrays, as well as external contamination and orbital debris environment.

Results

- Details will be presented by Jim Visentine (Boeing ISS External Contamination AIT).

Impact on ISS: Optical Property Degradation

- Optical properties degradation models were developed to estimate the change in α on an ISS functional surface. Models are based on:
  - Thickness of contaminant deposit
  - Solar exposure in equivalent sun hours
  - Laboratory and flight data covering silicone and hydrocarbon contamination
- Solar UV/VUV exposure increases contamination deposition by photochemical effects as well as making the deposit non-volatile via photochemical crosslinking
- Models predict α changes in reasonable agreement with existing data for deposit thicknesses in the 10^{-4} Å range and relatively high solar UV exposure.

Mir Contamination Observations Impact on ISS

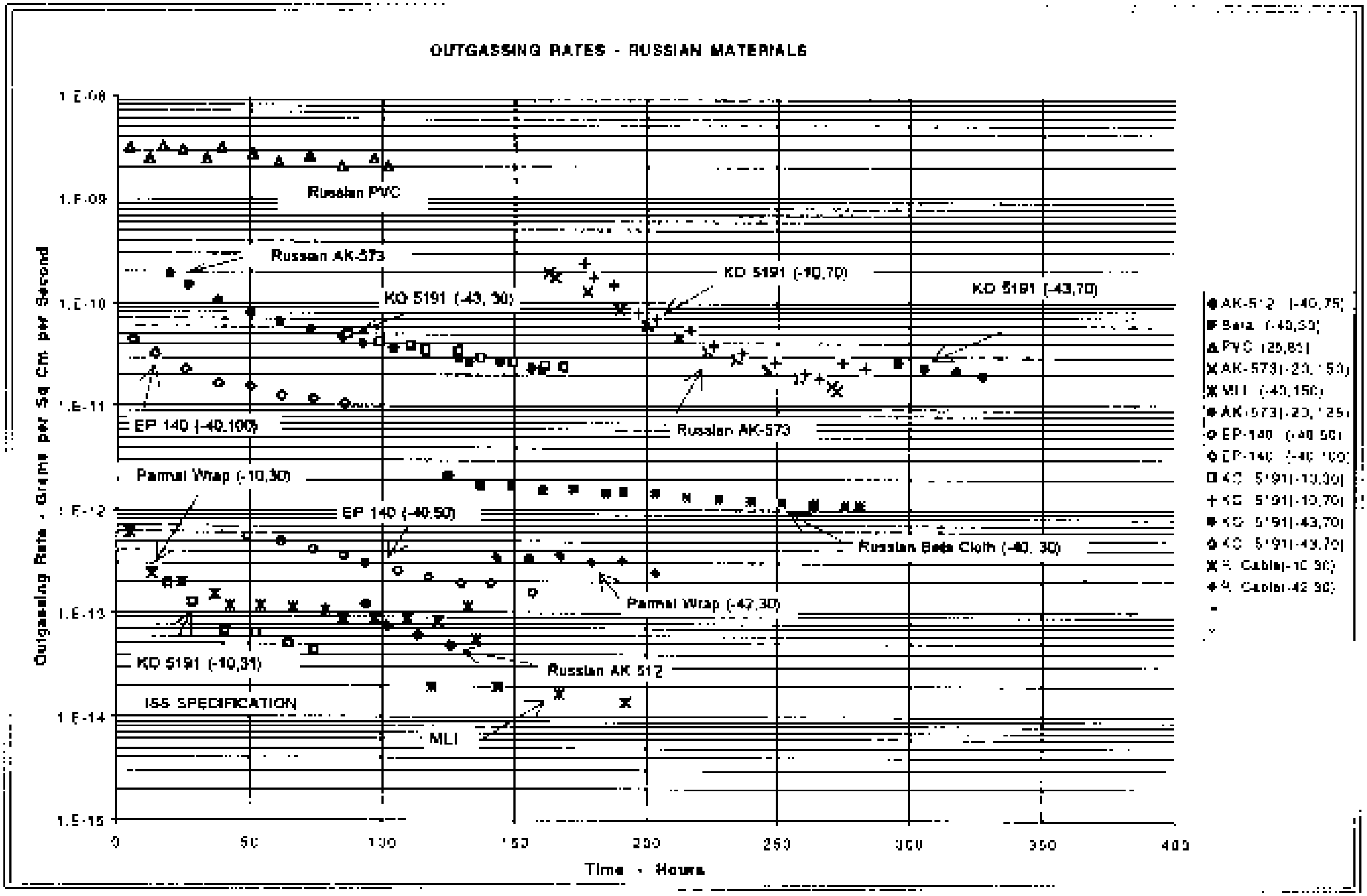
ISS ATCS Radiator Predictions Based on Mir Contamination Observations

α	Predictions Based on Euro-Mir 95 ICA External Contamination Observations	Predictions Based on Docking Module Camera Bracket External Contamination Observations	Predictions Based on Comes-Aragatz External Contamination Observations
Deposition: 1 Year	52030	3469	173
Deposition: 5 Years	260200	17340	867
Deposition: 10 Years	520300	34690	1734
ATCS Radiators, $\alpha_{1\ year}$	**0.28**	0.21	0.19
ATCS Radiators, $\alpha_{5\ years}$	**0.50**	**0.31**	0.21
ATCS Radiators, $\alpha_{10\ years}$	**0.59**	**0.39**	0.24

Russian Materials Testing

Materials	Mir	ISS	Test
Power Cable Insulation:			
PVC	X		X
Teflon		X	X
Parmal Wrap		X	X
TP-CO-2 (Z-93 Analog)	X	X	X
K0-5191	X	X	X
EP-140	X	X	X
Glass Fabric (Beta Cloth Analog):			
White	X	X	X
Black	X		X
MLI	X	X	X
Silicone Adhesive (Solar Arrays)	X	X	X
Adhesive Tape (LT-19)	X	X	X
AK-512	X	X	X
AK-573	X	X	X
BF-4 (Solar Panel Mesh Epoxy)	X	X	X
Solar Array Lubricant:			
Silicone	X	X	TBT
Fluorocarbon		X	-

Russia Materials Condensable Outgassing Rates



Conclusions

Comes-Aragatz

- Results are consistent with the estimated exposure: V side received the least amount of atomic oxygen fluence and the highest amount of UV, maintaining lower temperatures.
- The effective outgassing rates required to produce the observed contamination are consistent with typical large surface area Mir materials and coatings (such as KO-5191).
- KO-5191 (organic silicone based paint) probably was the major source of contamination since it coated a large composite section on the Mir Core Module that was viewed by the Comes-Aragatz experiment.
- Another silicone contamination source, although a lower order of magnitude contributor, is AK-573 (organic silicone based paint).

Conclusions

Docking Module Camera Bracket

- The effective outgassing rate required to produce the observed contamination is consistent with typical large surface area Mir materials and coatings.
- Silicone contamination sources: KO-5191 and AK-573 (organic silicone based paint).
- Hydrocarbon contamination sources: PVC cable insulation and BF-4 impregnated mesh (solar arrays).
- The higher source temperatures due to the Mir solar cycle and the fact that the Spektr module was a recent addition at this time would account for the higher rates inferred from the camera bracket contaminant deposit layer.

Conclusions

ICA Flight Experiment (Euro-Mir '95)

Russian Astra-II Flight Experiment

- Significant increases in ICA QCM frequency measurements correlate well with Mir attitude data and increase in temperature due to "solar cycles" (time in shadow).
- The effective outgassing rates required to produce the observed contamination are consistent with typical PVC rates. PVC is used for electrical cable insulation on the Spektr module.
- Pressure readings from within the Spektr endcone indicate significant materials outgassing from within the non-pressurized endcone.
- Correlation of ICA QCM frequency readings with Mir attitude data and pressure measurements from within the Spektr endcone indicate that materials outgassing and contaminant deposit re-release due to surface heating are the sources of contamination.

Risk Mitigation Activities

- The ISS External Contamination AIT has an on-going assessment of Mir external contamination observations, including analysis of data from several sources.
- Participants in analysis activities include NASA, Boeing, ESA/ ESTEC, RSC-Energia.
- Results have been instrumental in ISS Russian segment changes to ensure compliance with ISS external contamination requirements, for example:
  - Cable insulation on ISS Russian segment: Teflon instead of PVC
  - Replace high-outgassing KO-5191 and AK-573 with AK-512
  - Solar array lubricant: fluorocarbon instead of silicone

External Contamination Control Methodology

- Materials condensable outgassing rate testing is performed according to ASTM E 1559. Testing is long duration, typically from 100 to 300 hours.
    - ASTM E 595 test results are not reliable, or appropriate, to characterize external contamination materials sources.
    - Condensable outgassing rates are measured for a range of temperatures (material sample and QCM receivers).
    - Condensable outgassing rate data is curve fitted to account for time decay due to long on-orbit residence times.

External Contamination Control Methodology (cont.)

- External contamination modeling tools have been upgraded to analyze geometric models with up to 30,000 surface elements. Analysis tool can model variable geometry (solar array and radiator rotations), interactions between two spacecraft (approach, docking and separation of Orbiter and visiting vehicles.
- External contamination analysis is performed for every individual source and deposition estimates are obtained for all ISS surfaces.
- Master verification database summarizes cumulative estimated deposition rates for all ISS sensitive surfaces. It is also instrumental in identifying any potential issues.

External Contamination Control Methodology (cont.)

- Optical property degradation models have been developed to account for long on-orbit residence time and VUV exposure. Models are based on laboratory and flight data for both silicone and hydrocarbon contamination.

Additional Activities

- Orbiter waste water dump analysis
- Reviewing MEEP data
- Mir Solar Array Return analysis
- ISS re-flight of Phase I flight experiments